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By E. D. CLARK, R. W. CLOUGH and O. E. SHOSTROM
Laboratories of the Northwest Branch, National Canners Association, Seattle, Washington

THERE is hardly a subject connected with the canning of salmon that is so little understood as the matter of vacuum in the cans. As soon as the sanitary can came into use it became evident that some means would have to be taken to produce a vacuum in the cans, otherwise the ends would not stay collapsed. Through long years of experience the consumer of canned foods has learned to look askance at cans of any product which do not show collapsed ends. For that reason canners of all products find it desirable to produce sufficient vacuum in the cans so that the ends will remain concave under the conditions of temperature or altitude where the goods are marketed. Under certain conditions, such as occur when salmon cans are overfilled for instance, the contents may be entirely normal in every way though the ends of the cans may not be collapsed; however, swelling in a product like canned salmon is often a danger sign, and cans with badly bulged ends are unmerchantable.

The Nature of Vacuum

Vacuum is generally expressed in "inches of mercury" while pressure is expressed in "pounds to the square inch". It is unfortunate that both are not expressed in the same unit of measure since one is simply the reverse of the other. As darkness is the absence of light so vacuum is the absence of pressure. The earth is surrounded by an envelope of air which on account of its weight exerts a pressure upon the earth. The atmospheric pressure varies at different altitudes but at sea level is sufficient to support a column of mercury thirty inches high. An instrument which records this pressure is called a barometer. A column of mercury thirty inches high and having a cross section of

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one square inch weighs approximately fifteen pounds. From these two facts the two units of measure given above were derived.

If a can be closed without exhausting, the air within the can exerts the same pressure outwards as the atmosphere without exerts upon the can. Now if a part of the air be removed by exhaust, and the can closed, the remaining air exerts less pressure outwards than the atmosphere exerts upon the can and we say "a partial vacuum exists within the can". If the pressure within the can is sufficient to support a column of mercury 20 inches high and the atmospheric pressure is sufficient to support a column 30 inches high, then the difference between the height of the two columns, 10 inches, represents the "vacuum". This "vacuum" is what is meant whenever the word is used in this paper.

If a closed can be heated, the contents of the can tend to expand and exert a pressure outwards greater than the atmospheric pressure on the can and we say "a pressure exists within the can". Suppose this pressure in the can is sufficient to support a column of mercury 50 inches high and the atmospheric pressure is sufficient to support a column 30 inches high, then the difference between the height of the two columns, 20 inches, represents the "pressure". A column of mercury having a cross section of one square inch and 20 inches high weighs approximately 10 pounds. So we say "the can has a pressure of 10 pounds". This "pressure" is what is meant whenever the word is used in this paper. In speaking of total pressure within a can it will be called the total pressure. For example, the total pressure in the can above amounted to about 25 pounds, consisting of the atmospheric pressure of 15 pounds, and a "pressure" of 10 pounds.

In practice both vacuum and pressure are measured by means of suitable gauges. The vacuum gauge gives a reading in terms of inches of mercury, and shows the difference between the reduced pressure within the can and the atmospheric pressure outside. The pressure gauge gives a reading in terms of pounds per square inch, and shows the difference between the increased pressure within the can and the atmospheric pressure outside. A small compound gauge is now on the market which is so arranged and graduated as to show either vacuum or pressure. It has the appearance of the ordinary vacuum gauge used in testing canned foods but has the additional advantage that slight pressures, insufficient to cause the can to become a "springer" may be detected and measured.

In discussing vacuum in canned foods it must not be forgotten that the can is not rigid. The pressure exerted in piercing the metal of a can by the point of the gauge is sufficient to distort the can slightly and change its volume. This usually reduces the vacuum. For this reason the gauge should either be inserted just below the top seam where the distortion will be at a minimum, or, if used on the end, the pressure of the hand after the can is punctured should be relaxed sufficiently to permit the end to spring back. The highest reading thus obtained should be considered the vacuum of the can in question.

Since the can is not rigid, a high vacuum tends to distort it and decrease its volume. The internal pressure is so much lower than the external, that the sides of the can may be pressed in producing a panelled appearance. Canned salmon occasionally has this appearance while larger cans used with fruits and vegetables are frequently panelled. Such a distorted can will, of course, have a lower vacuum than it would have possessed had it retained its original shape. Furthermore, a pressure within a can tends to distort it and increase its volume. Any increase in volume will, of course, lower the pressure which the can would have possessed had it retained its original shape.

Manifestly it is impossible to calculate the distortions which the individual cans may undergo with changes of vacuum and pressure, therefore in this paper most of the tables and figures are based on the conduct of rigid containers. The reader should bear in mind that a non-rigid container, such as a tin can, would give lower values for both vacuum and pressure.

How Vacuum is Obtained

There are several different ways in which vacuum may be produced in canned salmon:

1. Exhausting by heat.*
    - (a) Moist heat.
    - (b) Dry heat.
2. Exhausting by mechanical means.
3. Disappearance of oxygen from the gases in the headspace.

1. **Exhausting by Heat**—This is the oldest and the commonest way of obtaining vacuum in canned salmon. The heat may be applied either (a) by moist steam in an exhaust box, or (b) by dry heat obtained by passing the salmon through a tube or jacket which is heated with steam at high pressure. The use of the exhaust box in the salmon industry came in with the introduction of the sanitary can. The period of exhaust and the temperature employed vary greatly, the present ten-

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*Note: In many food products a vacuum is frequently obtained by filling the food into the can while hot or by pouring hot syrup or brine over the food in the can.

dency being to increase the length of the exhaust. *Experience has shown that a short period of exhaust is not sufficient to produce a vacuum that will keep the ends of the cans collapsed under all conditions of temperature and altitude to which canned salmon may be subjected before it is consumed.* In the last four years this office has obtained data on the time of exhausting and processing in about 127 different salmon canneries located all the way from Northern California to the Yukon River in Alaska. Only eight of the 127 canneries gave no exhaust at all; eight exhausted mechanically by the use of vacuum closing machines, and 111 canneries by the use of heat, of which 57 exhausted with the cans open and 54 with the cans covered, that is the tops were loosely clinched on by the clinching machine. The average time of exhaust for those canneries which used exhaust boxes was 9¾ minutes. The average temperature of the exhaust box was about 208° F. It is seen then from these figures that at the present time it is the practice in most salmon canneries to exhaust for an average of about 10 minutes with live steam. There has been considerable disagreement as to whether it is better to exhaust with the cans covered or uncovered. Generally speaking it may be said that, considering all factors involved, it is better to exhaust with the cans loosely covered, as the covers prevent entrance of the condensed steam or any other matter while passing through the exhaust box, and they undoubtedly also assist in retaining heat in the cans between the time when they leave the exhaust box and the moment when they are closed in the closing machine.

Where vacuum is obtained by heat the amount obtained will depend to a great extent upon the temperature of the contents of the can and the amount of headspace at the time of closure. When vacuum is obtained by the use of a tube-type exhaust box, a can is subjected to a high degree of temperature for only a short time, while passing through the jacketed tube. This exposure of the can for a short time to high temperature undoubtedly serves to drive out a certain amount of air between the fish and the can and the headspace above the fish. However it is very difficult to get sufficient heat in the can without having too long a tube. For that reason the use of these exhaust tubes is rapidly falling off.

2. **Exhausting by Mechanical Means**—In this method the filled can with the lightly clinched cover passes into the chamber of the closing machine through a small door which closes hermetically. This chamber is connected with a large central tank in which a high vacuum is maintained by a separate pump. The lightly clinched

can subjected to this high vacuum loses a portion of its enclosed air, and while the vacuum thus produced within the can is maintained, the cover is tightly rolled on. The can now passes from the vacuum chamber and is placed in a tray made of iron strips and called a "cooler" because the can is later allowed to cool in it. It is then ready for the retort. A very satisfactory vacuum is usually obtained with this machine, on the average about 12 to 13 inches. As the amount of vacuum produced by this method is not dependent upon heating, there is naturally not the same amount of variation in vacuum with cans of various sizes and shapes as is observed when exhausting with steam. On the other hand, the can goes to the retort cold, instead of hot as when exhausted by heat, hence the cooking process must be somewhat longer, or carried on at a higher temperature, to effect sterilization.

3. **Vacuum Produced by Disappearance of Gaseous Oxygen**—All cans of salmon which are not completely filled, or in other words those having a headspace, contain immediately after closing some air consisting of about one-fifth oxygen and four-fifths nitrogen. The gaseous oxygen gradually disappears and is believed to enter into chemical combination with some constituent of the salmon. The rate at which the oxygen is absorbed varies with the different foodstuffs but with salmon is fairly rapid. Eighty per cent, or more, of the oxygen has been found to have disappeared within 24 hours after the cans were closed and retorted, while it has been found to be entirely absent in some cans of king salmon tested by us two days after packing.

As already stated, when a part of the air is removed from a can either by heating or by closing in a vacuum chamber, a partial vacuum is produced. In a similar way the disappearance as a gas of the enclosed oxygen results in a partial vacuum. Theoretically if all the air and other gases be removed from a rigid can, a nearly complete vacuum of about 30 inches would result. Therefore, if all the gaseous oxygen (amounting to one-fifth of the air present) be removed, a vacuum of several inches would be produced. By actual experiments in our laboratory, a vacuum of four to six inches has been obtained in non-exhausted, tightly-closed cans of salmon merely by this disappearance of gaseous oxygen. Of course in cans which have been exhausted, the disappearance of the enclosed gaseous oxygen would result in an increase in vacuum, proportional to the amount of air left in the can when closed. For various reasons the full amount of vacuum theoretically possible from this source is seldom obtained, two to four inches being more common than six inches. To summarize, this vacuum obtained by the disappearance of gaseous oxygen forms a real and noteworthy percentage of the total vacuum observed.

Reasons for Obtaining a Vacuum

There are several reasons for obtaining a vacuum in canned salmon. Among them are the following:

1. To keep the ends of the cans collapsed.
2. To prevent unnecessary strains upon the can during processing.
3. To restrict the growth of some micro-organisms.

1. **To Keep the Ends of the Can Collapsed**—This is very important since the external appearance of the can is the only indication we have as to the condition of the salmon within. Properly collapsed cans are usually, but not always, free from active spoilage, though they may of course contain fish which was spoiled when canned but which was properly exhausted and processed. On the other hand, active bacterial spoilage within the can will often result in swells and springers. For this reason all swells and most springers are regarded by the trade as unmerchantable. Furthermore some states have recently passed pure food regulations condemning all swells and springers. They may arise from causes other than spoilage however, and perfectly good salmon may be condemned for want of sufficient vacuum to hold the ends properly collapsed under the changing conditions of altitude or temperature, or both, to which the cans may be subjected. Shipments of salmon have recently been declared unmerchantable on account of the large number of springers and swells present, which have been produced simply by shipment to a higher altitude or a warmer climate. The possibilities of trouble in canned salmon from loss of vacuum are much greater than in many other canned products. Being packed at or near sea level and in the relatively cool climate of the North Pacific Coast, salmon is usually shipped to a higher altitude or a warmer climate. The natural laws involved and the amount of vacuum necessary to keep the ends of the cans collapsed will be discussed later.

2. **To Prevent Unnecessary Strains Upon the Cans During Processing**—During processing a considerable pressure is developed within the can, the amount of which depends primarily (1) upon the temperature of the retort, (2) the temperature of the contents of the can when sealed, or the vacuum produced by a vacuum closing machine, (3) the volume of headspace, and (4) the proportion of gases held within the tissues at the time of closure. Other conditions remaining the same, that can which receives the highest exhaust, either by heat or by vacuum machine, will develop the lowest internal pressure during the retorting. The pressure in a retort heated to 240° F. amounts to 10 pounds. Any pressure in a can, contained in this retort, in excess of 10 pounds will exert a strain upon the can. Suppose the pressure in such a can amounts to 30 pounds, a pressure of 10 pounds is compensated by the pressure in the retort but the remaining pressure of 20 pounds exerts a strain outward upon the can. Cans subjected to severe strain may become buckled or develop leaky seams. "Hot leaks", as they are called by salmon packers, may result but these frequently reseal themselves upon cooling and the contents may not spoil. However, occasional light weight or partially dry cans may be pro-

duced. Now suppose the can, referred to above, had been closed after a good exhaust and the internal pressure on being retorted at 240° F. amounted to only 20 pounds; 10 pounds of this pressure is balanced by the retort pressure and a pressure of only 10 pounds is left to exert a strain outward upon the can. For this reason a can is much less likely to become buckled or to develop leaky seams. With the pound and half-pound salmon cans this strain is not so serious as it is with Nos. 2½, 3 and 10 cans used in canning fruit and vegetables. With the latter serious loss may result. However even with salmon cans less loss occurs if the cans are exhausted before retorting and the strain on the cans thus considerably reduced. The difference between the internal and the external pressures of the cans during retorting is greatly increased at the end of the process when the steam pressure is reduced from ten pounds to zero. This has the effect of adding ten pounds of internal pressure to that already exerting a strain on the can. In some canneries this sudden increase in pressure strain is avoided by substituting air pressure for steam pressure in the retort. That is, when the supply of steam is turned off from the retort, air under pressure is passed in and the pressure within the retort maintained nearly constant while the cans are cooled with water. These devices are used more frequently with large cans than with those used in salmon canning.

3. **Restricting or Preventing the Growth of Certain Bacteria**—When the art of canning was first practiced, it was believed that food was preserved largely by the lack of oxygen in the container brought about by filling it as full as possible and by the expulsion of air by steam before the container was closed. Furthermore, after the theory that food spoilage was due largely to bacteria and not to air was advanced, it was rather generally believed that the absence of air would restrict or prevent their destructive action since some of them cannot grow in the absence of oxygen. Practically all spoilage in canned salmon is due to bacterial growth, usually occurring before canning but occasionally after the salmon is canned. Bacteria may be roughly divided into three groups according to their gaseous oxygen requirements:

(1) Aerobic, those which require atmospheric oxygen;

(2) Anaerobic, those which cannot grow in the presence of atmospheric oxygen; and

(3) Those which can grow in widely varying amounts of atmospheric oxygen.

It is obvious that if the oxygen be nearly all removed from a can by the exhausting process, the members of the first group will be restricted in their work of decomposition. On the other hand, it would seem that anaerobic bacteria should grow better in a well exhausted can on account of the smaller amount of oxygen present. Nevertheless experiments have been recently carried out in this laboratory which indicate that exhausting has some inhibiting effect on the growth of aerobic bacteria. In these experiments sterile cans of salmon were inoculated with certain aerobic spore-forming bacteria which had been obtained from non-sterile commercial cans of salmon. Part of the cans were exhausted and part were closed without exhaust. After standing at room temperature for several months the cans were examined bacteriologically. Those cans which were not exhausted showed uniformly greater bacterial growth than those cans which were exhausted.

Factors Influencing Vacuum

The amount of vacuum which a can will have is influenced by a number of factors, among which are the following:

1. Time and temperature of exhaust.
2. Fill of can or headspace.
3. Exhaust with cans open or with lightly clinched covers.
4. Delay between exhaust box and closing machine.
5. Loose or tight seams.
6. Fresh or stale fish.
7. Heavy can ends having several expansion rings or corrugations.

1. **Time and Temperature of Exhaust**—The amount of vacuum in a can of salmon is dependent to a large extent upon the temperature to which the contents of the can are raised before the cover is tightly rolled. This temperature depends upon that of the exhaust box and the time the can remains in it. There are three types of exhausting equipment used in the salmon industry, the most important of which consists of seven or more parallel chain carriers enclosed in a wooden box. Alternate chains run in opposite directions. The cans are deflected from chain to chain, traveling the length of the exhaust box on each of the carriers and finally issuing at the end opposite to that at which they entered. The time during which the cans are subjected to the heat depends upon the number of carriers, the length of the box and the speed at which the chains are driven. The exhaust boxes are heated by steam and the temperature varies according to the temperature of the steam as supplied to the box, the amount of steam supplied and the leakage of steam from the box. The temperature seldom reaches 210° F. and frequently falls to 204° F., or even lower. The time varies from six to sixteen minutes.

A second type of exhaust box contains a series of large discs, engaging each other by means of cogs. The cans travel near the edge of the discs and are guided from one disc to another until they issue at the other end. The box is heated by steam, the temperature and time varying as in the case of the chain carrier exhaust box.

A third type of exhaust equipment consists of a steam jacketed iron tube, through which the cans travel on a chain carrier and are subjected to a fairly high temperature for two or three minutes. Although the temperature is much higher than in the other types of exhaust, the shorter period of time results in a lower vacuum than that obtained by either of the other types. This style was devised in order to economize in space but the increase in temperature does not compensate for the decrease in time and the resulting vacuum is unsatisfactory. However in some cases two of the tubes have been used, either side by side, or end to end, and the cans passed through both, thus doubling the time of exposure to the heat and creating a better vacuum.

Present practice in exhaust varies greatly both in time and temperature. More uniform procedure would result in a more uniform product.

2. **Fill of Can or Headspace**—The ordinary can of salmon has a small space at the top of the can filled only by gases and water vapor. This space is known as the "headspace" and varies from almost nothing to a half inch in height. The average for salmon is a little less than one-fourth inch at ordinary room temperature. The amount

of headspace in a can is of considerable importance from the standpoint of vacuum. In general it may be said that the less headspace there is in the unexhausted, unsealed can the higher the vacuum in the exhausted, sealed, retorted and cooled can will be.

When the unsealed can mentioned above is heated in the exhaust box a number of things take place, the more important of which will be mentioned and their separate effect on the ultimate vacuum described.

A. The liquid and solid contents of the can expand. The exact amount which water will expand when heated one degree is known. Whether the salmon flesh will expand the same amount is not known but inasmuch as about 70% of the flesh is water it is reasonably safe to assume that it will expand at about the same rate. As the liquid and solid contents expand, the headspace grows smaller and a part of the gas (mostly air) in the headspace is forced out of the can. Now if the can be sealed and cooled to its initial temperature, the liquid and solid contents will contract and return to the initial volume. There will be the same amount of headspace as before but there will be less gas to fill it. Since there is less gas to fill the same volume the gas will exert less pressure within the can than is exerted by the atmospheric pressure outside. In other words, there will be a partial vacuum in the can. In extreme cases where the initial headspace is small, the expansion of the liquid and solid contents during exhaust may be sufficient to completely fill the can and force out all of the gases. If the can be sealed and cooled to its initial temperature, the contents will contract and a headspace will again appear but there will be no gas to fill it. The water vapor will exert a slight pressure (definite amount for each temperature) and with this exception there will be a complete vacuum in the headspace.

B. The vapor pressure of the water in the can increases as the temperature increases. While the can is unsealed, the combined pressure of the water vapor and the gases within the headspace equal the pressure of the atmosphere outside. Therefore when the pressure of the water vapor increases with increase in temperature the pressure of the other gases must decrease in order to keep the total pressure (equal to the atmosphere) constant. Since, as we have seen under A, the headspace does not grow larger during the exhaust (but rather smaller) the lowering of the pressure due to the gases, shows there is a smaller amount of them present. A part of the gases have been forced out by the water vapor. Now if the can be sealed and cooled to the initial temperature, the pressure of the water vapor will also return to the lower initial pressure. There will be less pressure in the can and, since pressure and vacuum are inversely related to each other, the lowering of the pressure will produce a partial vacuum. The partial vacuum due to the decrease in vapor pressure may be calculated by subtracting the vapor pressure at the initial temperature from that at the sealing temperature. For example, the vapor pressure of water at 132° F., measured in inches of mercury, is 4.75 while at 72° F. it is only 0.78. Sealing a can at 132° F. and cooling it to 72° F. would lower the vapor pressure from 4.75 to 0.78 and produce a vacuum of almost four inches by this factor alone.

C. The gases in the headspace of the can also expand with increasing temperature and since the headspace does not increase (but rather decreases) a part of the gases are forced out during the exhaust. On cooling to the initial temperature the liquid and solid contents contract and the initial headspace is again obtained. But on account of the loss of a part of the gases forced out of the can (a) by the expansion of the liquid and solid contents, (b) by the increase in vapor pressures, and (c) by the expansion of the gases themselves, a considerably smaller amount of the gases is now left to fill the initial headspace. This smaller amount of gases will then exert less pressure than the larger amount of gases which was in the headspace before exhaust and this decrease in pressure will, of course, create a partial vacuum.

Table 1 shows the amount of vacuum produced by each of these factors in a one-pound tall salmon can containing 432 grams of distilled water and 29.92 cc. of headspace at time of sealing, and sealed when the contents had reached 132° F. The can when cooled to the temperatures given in the table will theoretically have the vacuums given in the last column. These values are of course theoretical and treat the can as a rigid container. Since the can is not rigid it would tend to decrease in volume and this would also somewhat decrease the vacuum.

Table 1—Influence of various factors on the total vacuum produced in a one-pound tall salmon can containing 432 grams of distilled water and having 29.92 cc. headspace when heated to 132° F., sealed, and cooled to various temperatures. Atmospheric pressure equals 29.92 inches of mercury.

	Vacuum due to			
Can cooled to Degree F.	Contraction of water	Decrease in vapor pressure	Cooling of gases	Total vacuum inches of mercury
32	3.64	4.57	4.26	12.47
42	3.74	4.48	3.83	12.05
52	3.69	4.36	3.41	11.46
62	3.74	4.19	2.98	10.91
72	3.57	3.97	2.55	10.09
82	3.31	3.66	2.13	9.10
92	2.97	3.25	1.70	7.92
102	2.50	2.71	1.28	6.49
112	1.87	2.02	0.85	4.74
122	1.10	1.13	0.43	2.66

The principal changes which take place when a can is exhausted have been discussed. Various other changes take place during the exhausting and retorting of a can of salmon, such as (a) the transference of gas from the flesh to the headspace, (b) the disappearance from the headspace of nearly all or all of the oxygen, and (c) the changes in volume of the can due (1) to the expansion and contraction of the metal and (2) to changes in shape. Only one of these, that is the expansion of the metal, can be calculated with approximate accuracy and its effect on vacuum is very small. The others will vary greatly with different cans and cannot be predicted with accuracy.

It has already been stated that the amount of headspace is of considerable importance from the standpoint of vacuum. The effect of different amounts of headspace on the vacuum obtained when using a rigid container was determined both theoretically and experimentally and the results expressed graphically in Figs 1 and 2. The apparatus used is shown in Fig 1. It consists of a heavy copper sphere having a capacity very nearly the same as that of a one pound tall salmon can. This copper sphere approaches closely a rigid container. It was equipped with two stuffing boxes, one holding a thermometer and the other a capillary tube provided with a stopcock. The sphere was filled (by weight) with water to the proper headspace at the initial temperature (70° F) and then, with the stopcock open, was heated to the desired temperature, the stopcock closed, and the sphere cooled to the initial temperature when the amount of vacuum was read by means of a manometer. This was repeated for each fill or amount of headspace and the values obtained used in constructing the experimental curves in Figs. 1 and 2.

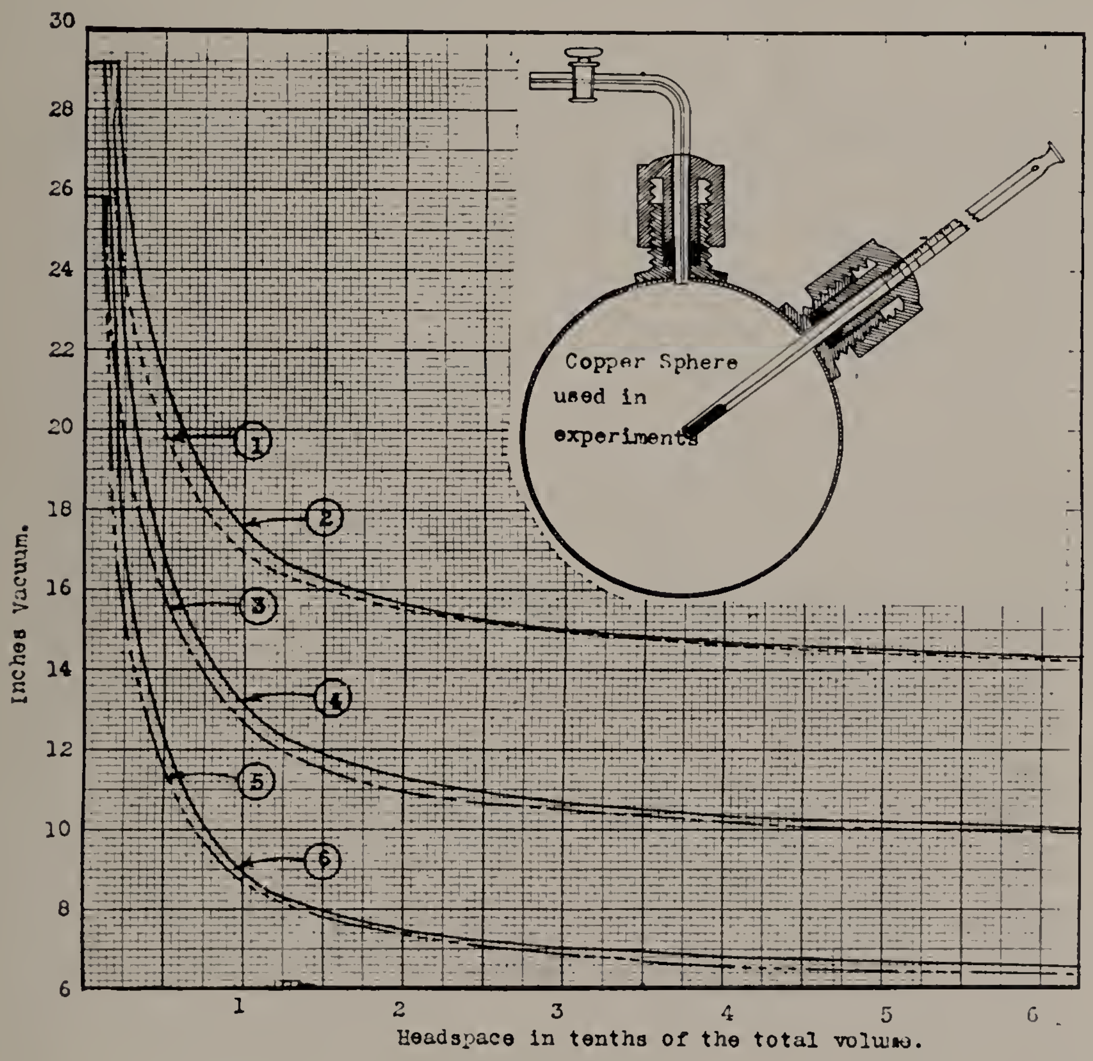

Fig. 1.—Effect of Headspace on Vacuum in Rigid Container.

Explanation—The data from which the experimental curves were developed were obtained by the use of a copper sphere (see sketch in upper right-hand corner), filled with water to the desired headspace at 70° F., heated to the required temperature, closed, cooled to 70° F., and the vacuum for each fill determined by the use of a manometer.

Curve Number	Temperature Range	Description
1	170-70	Experimental curve.
2	170-70	Resultant theoretical curve for air, water, and water vapor.
3	150-70	Experimental curve.
4	150-70	Resultant theoretical curve for air, water, and water vapor.
5	130-70	Experimental curve.
6	130-70	Resultant theoretical curve for air, water, and water vapor.

The data for the theoretical curves was obtained by calculating the resultant effect of the changes in volume of water, in vapor pressure, and in the pressure of the gases present. These have been described already rather fully. The theoretical curves in Fig 1 apply to any size can, but assume that the can is rigid. It will be seen that if the can is full at the initial temperature, or full enough so that it becomes full when heated to the desired temperature, then on sealing and cooling, a complete vacuum, with the exception of a slight vapor pressure, should result. It will be noticed that the curves drop very sharply from the vacuum produced in a full can to that produced in a can only nine-tenths full. From this point the curve is much more gradual and in fact becomes almost flat. In other words, the amount of headspace would have little effect on the vacuum in cans ranging from nine-tenths full to

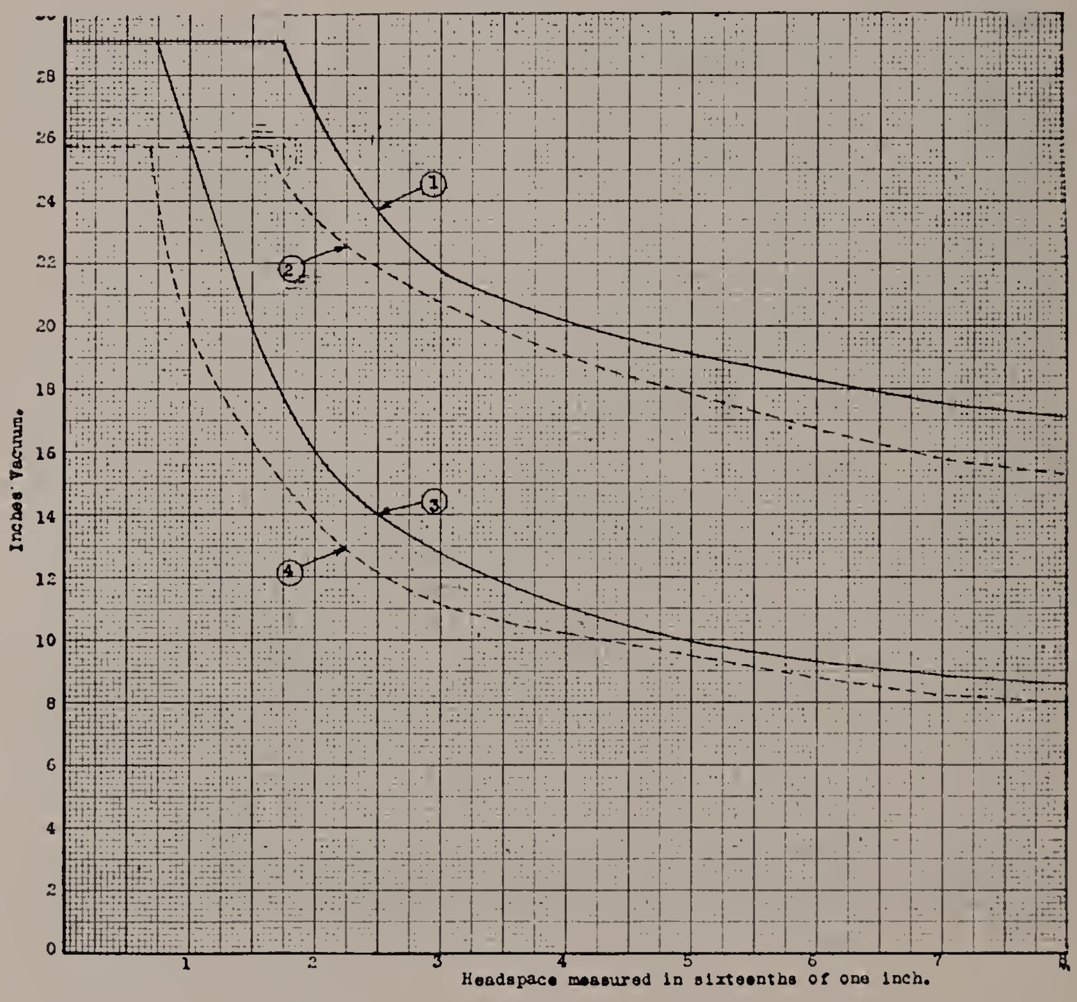

Fig. 2.—Relation of Headspace to Vacuum in Tall Salmon Can.

Explanation.—Data from which experimental curves were developed were obtained by use of copper sphere shown in Fig. 1. The various headspaces used in the copper sphere were equivalent to headspaces in 1-lb. tall salmon cans measured in sixteenths of an inch. The copper sphere was filled with water to the desired headspace at 70° F., heated to the required temperature, closed, cooled to 70° F., and the vacuum for each fill determined by the use of a manometer.

Curve Number	Temperature Range °F.	Description
1	170-70	Resultant theoretical curve for air, water, and water vapor.
2	170-70	Experimental curve.
3	130-70	Resultant theoretical curve for air, water, and water vapor.
4	130-70	Experimental curve.

nearly empty. Such cans are not commercial cans and these curves are given only to show the extreme effects of headspace.

Fig. 2 shows the relation of headspace to vacuum in a one-pound tall salmon can. The values given are based on the assumption that the can is rigid. The experimental values were obtained by the use of the copper sphere already described. The headspaces used in the sphere were such as to be equivalent to sixteenths of an inch in a one-pound tall salmon can holding 468 grams of water. Curve No. 1 shows that even though the can had a headspace of nearly two-sixteenths of an inch at 70° F, the liquid contents would expand and completely fill the can at 170° F. If the can were closed at this temperature and cooled to 70° F a complete vacuum, with the exception of a slight vapor pressure, would result. From a headspace of about two-sixteenths of an inch to one of three-sixteenths the curve drops rather sharply, showing that the amount of headspace has a great influence on the final vacuum. From this point the curve is more gradual and between a headspace of three and one of five-sixteenths of an inch, within which limits most of the salmon cans tested have been included, a difference of less than three inches is found. Curve No. 2 was obtained experimentally by the use of the copper sphere shown in Fig. 1. It follows the theoretical curve (curve No. 1) very closely. Practically the same results would have been obtained with a one-pound tall salmon can, provided the can had been rigid. Curves Nos. 3 and 4 were obtained in the same way as Nos. 1 and 2 except that the temperature range was only 70° to 130° F instead of 70° to 170° F. This range of temperature is probably more nearly that which obtains in the salmon industry than the temperature range of 70-170° F. In other words, more cans of salmon reach a temperature of 130° F. during the exhaust than reach the higher temperature of 170° F.

The effect of amount of headspace on vacuum has thus far been considered from the standpoint of the amount of headspace in the can before exhausting and closing. It has been shown that if the cans were rigid, then the smaller the headspace, within certain limits, the larger the amount of vacuum secured would be. For instance, in Fig. 2, curve 3 shows that a headspace of two-sixteenths of an inch would theoretically give a vacuum of 16 inches, while four-sixteenths would give about 11 inches. Since the cans are not rigid, sufficient headspace should be allowed to insure that a headspace will remain even after the can has contracted in cooling. It appears that a headspace of three or four-sixteenths of an inch is desirable in one-pound tall salmon cans.

The effect of amount of headspace on vacuum when considered from the standpoint of the amount of headspace in the exhausted, closed, retorted and cooled can will now be discussed. This is, of course, the commercial can as ready to be marketed. What increase in temperature will be necessary to cause the can to lose all its vacuum? This depends to a great extent upon the amount of headspace in the can. Fig. 3 gives a series of curves showing the loss in vacuum with headspaces ranging from one to six-sixteenths. The curves are theoretical and based on a one-pound tall salmon can having a vacuum of 8 inches at 52° F. Eight inches is about the average vacuum found in canned salmon. Most canned salmon when inspected at Pacific Coast ports is at a temperature of 52° F or less. Curve 1 shows that if the can had one-sixteenth of an inch headspace it would lose all its vacuum at a temperature of 80° F, i. e., it crosses the zero line near the point where the vertical line representing 80° F. intersects the zero line.

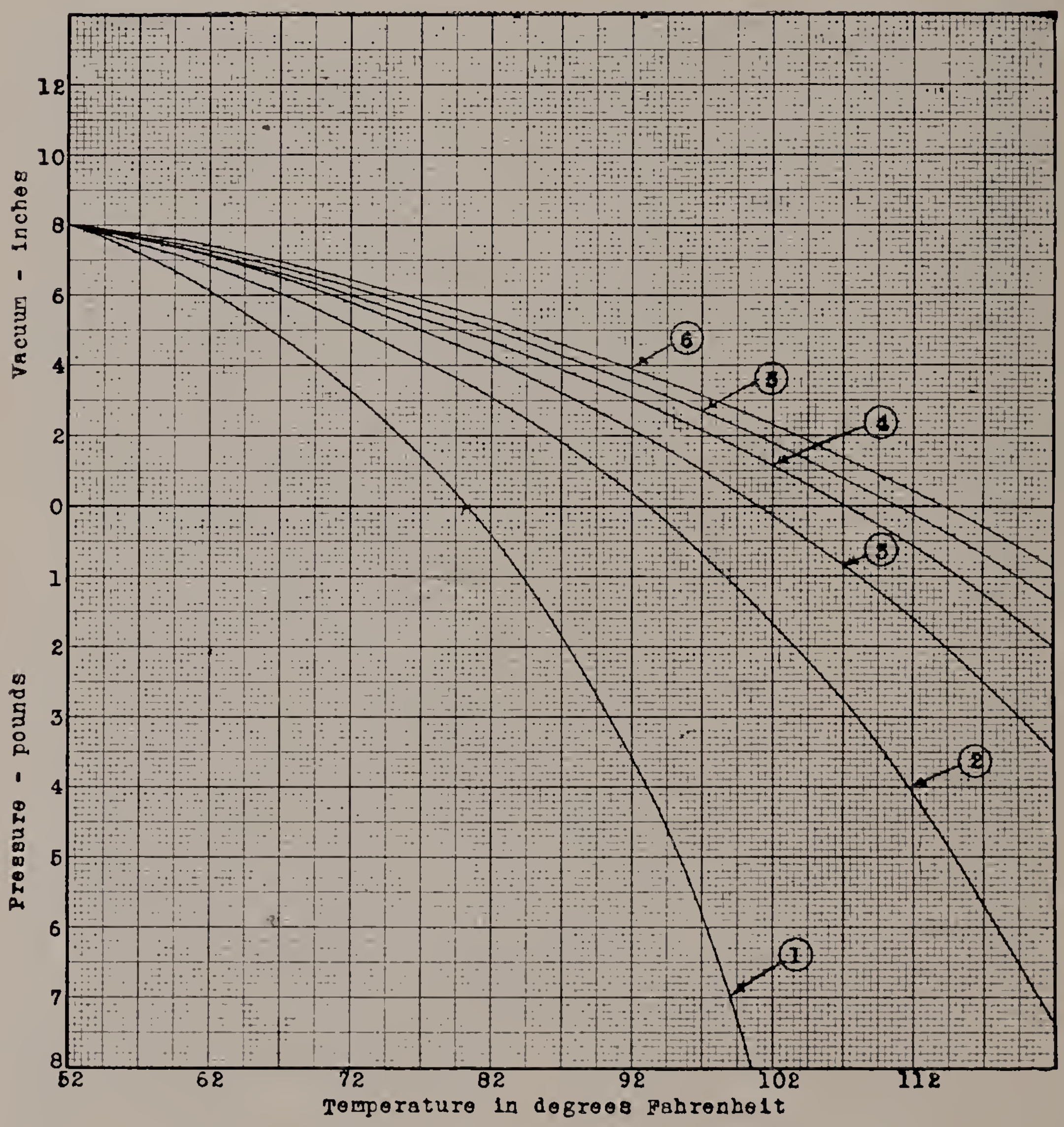

Fig. 3.—Resultant Theoretical Curves for Air, Water and Water Vapor in a 1-lb. Tall Salmon Can Having Different Amounts of Headspace.

Curve Number	Headspace Sixteenths of one inch
1	1
2	2
3	3
4	4
5	5
6	6

Can is assumed to be rigid.

Curve 2 shows that if the can had two-sixteenths of an inch headspace, it would lose all its vacuum at a temperature of 93° F. Curves 3, 4, 5 and 6, representing headspaces of three, four, five and six sixteenths of an inch, cross the zero line at 101, 107, 111, 114° F. respectively. These curves show that with cans ready for the market, those cans which have the most headspace for any given vacuum will be the safest cans to ship to a place having a warm climate. For example, it would be poor policy to ship a parcel of canned salmon whose average headspace was only one or two-sixteenths of an inch, and whose average vacuum was eight inches or less, to a market like New Orleans or Manila. If this were done claims for springers would almost surely result.

While **temperature** and amount of headspace are inimately related in their influence on vacuum, **altitude** and the amount of headspace are not directly related. For example, if six cans having headspaces of one, two, three, four, five and six-sixteenths of an inch and a vacuum of 5 inches each at sea level be sent to Denver, Colorado, at an elevation of some 5,000 feet, each of the cans will have lost practically all of its vacuum. The headspace will have exercised no influence on the result. It is understood that the temperature at both sea level and Denver are the same during the experiment.

Now if the same six cans be sent to Leadville, at an elevation of some 10,000 feet, there would be a pressure in the cans in excess of the atmospheric pressure outside. If the cans were rigid this excess pressure would be about two pounds per square inch in each can.

3. **Exhaust With Cans Open or With Lightly Clinched Covers.**—When the sanitary can was first adopted in the salmon industry the filled cans were often passed through the exhaust boxes open; however, on account of the condensation of steam in the boxes and consequent drip of water into the cans and the loss of small pieces of the fish in the passage through the box, resulting in an insanitary condition of the box, this practice was not altogether satisfactory. As a remedy the cans were passed from the filler to a machine in which the covers were loosely clinched, permitting the escape of air and gases while passing through the exhaust box but preventing the entrance of water and solid matter. This method is superior to the open can exhaust since it results in a better looking and more sanitary pack. It appears probable that the can contents retain heat better with the top lighly clinched on than with the open can during the passage from the exhaust box to the closing machine where the top is firmly rolled on. This retention of heat results in a higher vacuum.

4. **Delay Between Exhaust Box and Closing Machine.**—Any delay at this point results in a loss of heat in the cans and a consequent loss of vacuum. The closing machine should therefore be placed as near the exhaust box as practical and every precaution taken to ensure the steady progress of the cans from one to the other. In case the exhaust box stops running, the cans between the box and the closing machine should be passed through the latter at once and not allowed to cool while the box is being started again. Overlooking this precaution is undoubtedly sometimes responsible for the presence of an occasional can which has a low vacuum in a parcel whose average vacuum is much higher.

5. **Loose or Tight Seams.**—All seams should be made as tight as possible in order that there may be no loss of vacuum during the retorting or subsequent cooling and storage. Loosely rolled seams frequently result in "breathers" with consequent loss of vacuum and sometimes spoilage. On the other hand, loosely rolled seams may result at times in a high vacuum. Such cans on being subjected to high internal pressure during retorting may lose through the sprung seam a portion of the air or other gases still remaining in the can. This seam on cooling even slightly may reseal itself. Subsequently on further cooling a high vacuum may be produced. Vacuums as high as 17 or 18 inches have been obtained experimentally in our laboratory with both pound and half pound cans. These cans had not been exhausted at all before retorting, but their seams had intentionally been rather loosely rolled. Vacuum obtained in this way may be designated as "retort" or "process" vacuum.

6. **Fresh or Stale Fish.**—From a study of the gases in the headspace of canned salmon we have determined that carbon-dioxide gas is always present, but that the amount is much higher in cans containing stale or tainted fish than in cans of good salmon. Cans of salmon packed when the fish had been out of water only six hours contained from 7 to 9 per cent of carbon-dioxide. Since no bacterial decomposition could have taken place, we believe that most of this gas had been driven from the cells of the flesh where it was formed during the normal life processes of the fish. In stale or tainted fish this normal quantity of carbon-dioxide is added to by the activities of bacteria. Such stale or tainted raw fish, if closely examined, will be found to have tiny pockets of gas under the membranes and distributed through the tissues. On retorting most of this gas is driven into the headspace of the can

Furthermore, a considerable amount of hydrogen gas, amounting in extreme cases to 40 or 50 per cent of the total gas present, is frequently found in the headspace of cans of tainted salmon, but none has been found in cans of good salmon. Not all of the species of bacteria which decompose salmon produce hydrogen and therefore it is not always found in cans of tainted salmon. This gas is not a normal product to be found in the tissue cells of the live salmon but is frequently formed in the tissues by bacterial action during decomposition. Therefore it appears that its presence in the headspace of canned salmon may be accepted as evidence of some degree of spoilage.

The presence in sterile cans of these gases, which for the most part are driven from the salmon flesh during the exhaust and cooling, might possibly be expected to lower the vacuum in the can. However, it seems reasonable that these gases must have occupied a considerable space in the flesh of the salmon before retorting. They are driven into the headspace of the can during processing and will have only a small effect on the vacuum; that is, they will occupy nearly the same space in the headspace of the can as in the salmon flesh. Experimental results obtained in this laboratory tend to support this deduction. The vacuum and the composition of the gas in the headspace in each of 390 cans was determined. These cans were taken from an experimental lot of salmon packed to show progressive decomposition during a six-day period of spoilage under average cannery conditions. The samples used consisted of sixty-five cans from each of the six days' pack. The average percentage of carbon-dioxide and hydrogen increased each day but no appreciable difference in the average vacuum from day to day was observed. It appears probable, therefore, that the condition of the salmon, as regards decomposition, has little effect upon the vacuum obtained in the exhaust.

7. **Use of Heavy Tin Plate Having Several Expansion Rings (or Corrugations.)**—A few canneries use heavy ends with several expansion rings in their cans and do not exhaust them. These ends are very rigid and may be sprung in or out only by the exercise of considerable pressure. By the use of these ends, cans having little or no vacuum may be subjected to marked changes in temperature or altitude or both, without visible effect on the can; springers or swells would not result as when ordinary can ends are used. On the other hand, pressures developed in the cans from bacterial action due to under-processing would have to be correspondingly high before the can would take on an abnormal appearance. The swollen appearance of under-processed cans is relied upon by the packer and the vendor as a means of detecting such under-processed cans and of keeping them from the consumer. This swollen appearance acts as a safeguard to the consumer and also to the packer who would much rather lose a can of salmon than a customer. With the use of such heavy can ends

there is danger that under-processed cans may spoil and no indication of such spoilage be evident from the appearance of the can. The purchaser of such a spoiled can of salmon is very likely to develop a dislike for canned salmon.

Storage or Shipping Conditions Influencing Vacuum

Among the storage or shipping conditions which influence vacuum are the following:

1. Temperature.
2. Altitude.

1. **Temperature.**—As has already been stated, the contents of a can expand when the temperature increases and contract when it decreases. Therefore, cans which have a low vacuum, or none at all, when tested at 42° to 52° F may have 3.5 to 4 inches (1.7-2 pounds) pressure when held at 92° F. This may be sufficient to produce springers and to render the cans unmerchantable. There have been numerous instances where considerable losses have occurred simply from shipping low vacuum salmon to places having a higher temperature. In one instance at least the salmon cans on being shipped back to the cooler climate returned to their normal appearance. Considerable expense and vexation may be avoided if only salmon having a good vacuum is shipped to tropical countries or warm localities in the United States. The question arises as to how much vacuum is required to keep cans from becoming springers or swells at any given temperature.

Table 2 and the curves based on it will enable one to answer this question with a considerable degree of accuracy.

The values given in table 2 are calculated from the combined results of the effect of changes of temperature on the liquid and solid contents of the can, on the water vapor pressure and on the gases in the can. The expansion or contraction of the liquid and solid contents was considered to be the same as would occur if the material were distilled water alone. The values are based on a table given in Van Nostrand's Chemical Annual, 1st edition, page 383. The values for vapor pressure are those given in Kent's Mechanical Engineer's Pocket Book, 8th edition, page 586. Changes in the pressure of the gases in the can are based partly on the same table and partly on the well known laws governing the behavior of gases.

The calculations are based on a one-pound tall salmon can containing 438 grams of distilled water and 29.92 cc. of headspace (about one-fourth inch) at 72° F. and sea level. The can is assumed to be rigid and thus to suffer no distortion with changes in vacuum or pressure. Since the purpose of the table is to indicate the temperature at which a can may become a springer, we are not concerned as to what the exact pressure within the can may be, but we are concerned with the point at which the can ceases to have a vacuum and takes on a pressure. This is the danger point and any further increase in temperature may result in a "springer." Of course when the can becomes a "springer" its volume is increased and this will lower the pressure within the can to some extent. However, we are not so much concerned with the amount of pressure within the can after it has become a springer as we are with the fact that it has become a springer and therefore unmerchantable.

Explanation of Table 2 and Figure 4:

To use this table one should determine the vacuum or pressure in the can by means of the compound vacuum-pressure gauge already described. For most purposes the ordinary vacuum gauge is sufficient, but there are times when it is desirable to be able to measure the pressure of certain cans. At times cans which appear to have a vacuum in that the ends are collapsed, will prove to have a half-pound or a pound of pressure, which was not sufficient to cause the can to act as a springer. With a compound gauge the exact amount of this pressure can be determined whereas with a vacuum gauge alone, one would only know that the can had no vacuum. Having determined the vacuum one should next determine the temperature of the contents of the can in degrees Fahrenheit. Unless this temperature is approximately that of the room in which the cans are examined, it is very diffiicult to determine it accurately; therefore, in cutting canned salmon it is best to hold the samples in the room where they are to be examined for twenty-four to forty-eight hours, in order that the cans may come to the temperature of the room. Warming the cans to the temperature of the cutting room has the further advantages, first, that the oil makes a better showing in the can, and second, that odors of decomposition, if present, are more easily detected. Having determined the vacuum and the temperature, one is in a position to consult the table and ascertain what the vacuum or pressure would theoretically be at any other temperature; for example, the maximum temperature at the place to which it is proposed to ship the salmon.

To use table 2: Find the temperature in the first left hand column which is nearest to the temperature of the can of salmon (which should be that of the cutting room), then follow the **horizontal** row of figures to the right until that nearest to the vacuum of the can in question is found, then the figures in that **vertical** column above or below represent in inches or pressure in pounds which the can would have at the temperature in the first left hand column in line with those figures. For example, if a can of salmon with a headspace of one-fourth inch at 62° F has a vacuum of 2.6 inches, it would have a vacuum of about 1.4 inches at

72° F and no vacuum at 82° F., while at 102° F.. it would have a pressure of about 1.9 pounds. Again, if a can with the average amount of headspace (one-fourth inch) tested at 52° F has 2.2 inches of vacuum, it would have about 1.2 inches at 62° F and none at 72° F, while at 82° F. it would have a pressure of about 0.75 pound and at 102° F., about 2.7 pounds. This table may be used only for points at or near sea level, or between points of approximately the same elevation. As explained later, changes in altitude also greatly affect the vacuum.

Table 2—The influence of storage temperature on the vacuum of salmon cans at sea-level.

Temp ° F.	Inches of vacuum or pounds pressure in closed cans at different temperatures.						
42	1.9	3.0	4.3	5.8	7.3	9.0	10.8
52	1.0	2.2	3.6	5.0	6.7	8.4	10.2
62	0	1.2	2.6	4.1	5.7	7.6	9.5
72	0.6	0	1.4	3.0	4.7	6.6	8.5
82	1.4	0.75	0	1.6	3.3	5.3	7.4
92	2.3	1.6	0.9	0	1.8	3.9	6.0
102	3.4	2.7	1.9	1.0	0	2.1	4.3
112	4.8	4.0	3.1	2.1	1.1	0	2.4
122	6.3	5.5	4.5	3.5	2.4	1.3	0

NOTE—The figures above the diagonal line of zeros represent vacuum in inches of mercury while the figures below represent pressure in pounds per square inch. The can is assumed to be rigid. The values are theoretical and are based on a one pound tall salmon can containing 438 grams of distilled water and 29.92 cc. of headspace (about one-fourth inch) at 72° F. However, the vacuum or pressure in a one pound tall can of salmon having the same amount of headspace would change in about the same way.

For a better understanding of changes which take place in the vacuum of canned salmon with changes of temperature, the curves given in Figure 4 were prepared. These curves are derived from the data given in table 2.

The heavy line across the page marked "O" represents the point at which the cans have neither vacuum nor pressure; above this line all values represent vacuum in inches of mercury and below all values represent pressure in pounds per square inch. Horizontal lines represent vacuum or pressure, while vertical lines represent tem-

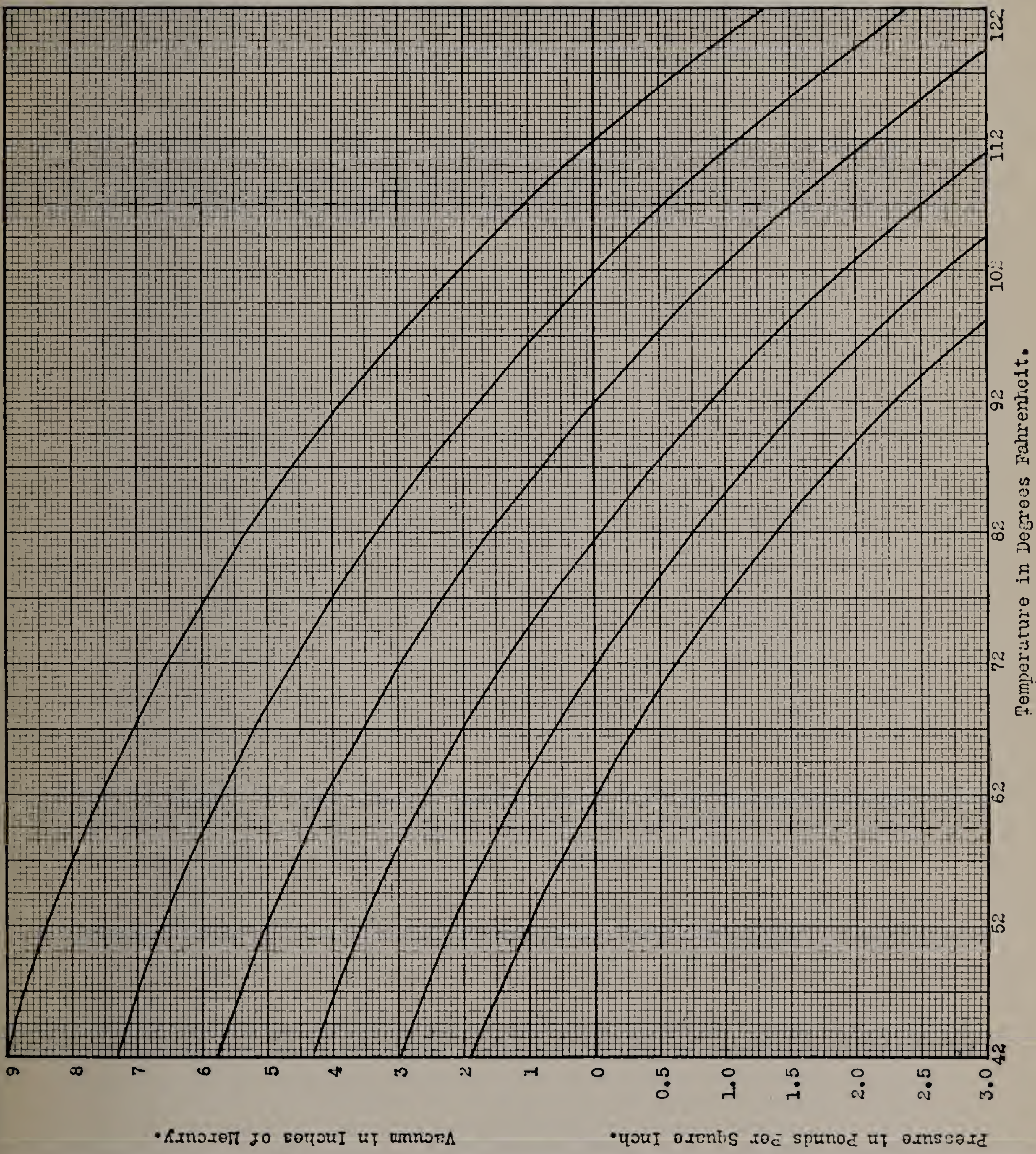

Fig. 4—Relation Between Storage Temperature and Vacuum.

perature in degrees Fahrenheit. Vacuum or pressure in a can of salmon will change with changes of temperature very closely according to the curves which have been drawn. This chart is used as follows: Find the temperature at the foot of the vertical line which is nearest to the temperature of the can of salmon; next locate the vacuum at the side of the page which is nearest to the vacuum found in the can of salmon; follow the horizontal line representing the vacuum until it crosses the vertical line representing the temperature. The point of intersection will fall near some curve on the chart. Now the can in question would vary in vacuum or pressure with changes in temperature rather closely in accordance with this curve. For example, if a can with a headspace of one-fourth inch at 62° F. has a vacuum of 2.6 inches, it will be seen by following the nearest curve that it would have a vacuum of about 1.4 inches at 72° F. and no vacuum at 82° F. where the curve crosses the zero (O) line, while at 102° F. it would have a pressure of about 1.85 pound. The vacuum or pressure in this particular can for any other temperature lies in this curve at the point where the vertical line representing that temperature crosses the curve. By following the horizontal line nearest to this intersection to the edge of the chart the vacuum or pressure may be read. Again, suppose the can in question has a vacuum of 2.2 inches and the temperature is 52° F. The vertical line representing 52° F. and the horizontal line representing 2.2 inches intersect on the curve which reaches the edge of the chart near the figure 3 and crosses the zero line where it intersects with the vertical line representing 72° F. This means that at 72° F. this can would have no vacuum, while at 42° F. it would have about 3.0 inches; furthermore, at 102° F. it would have about 2.7 pounds pressure.

Low Vacuum Produces Springers

These curves and the table show in a practical way whether it is safe to send a parcel of salmon having the average headspace and whose vacuum is known to any given country or locality where the maximum temperature is known. As already stated cans having a low vacuum have almost the same pressure exerted by the gases within the can as is exerted by the atmospheric pressure outside. Consequently when the ends of such cans have been sprung outward the atmospheric pressure is often inadequate to force them back to their original position even when the normal temperature conditions return. Therefore, cans which have been subjected for a few days to an abnormally high temperature may not collapse again even when the normal temperature conditions return. For this reason the packer should see to it that his cans have sufficient vacuum to keep the ends collapsed even when subjected to the maximum temperature of the place to which the salmon is to be shipped.

In this connection, consideration must also be given to the route over which the salmon is to be shipped. The salmon in transit may pass through a section of territory having a climate much warmer than that of the place to which the salmon is consigned. Cans having a low vacuum may become springers. These cans as stated above may remain springers even after the temperature has fallen low enough to reduce the pressure within the can sufficiently to again produce a vacuum.

In discussing springers it must be remembered that the ends of such cans are not absolutely free to move in and out with changes in vacuum and pressure. They are controlled to a considerable extent by the thickness of the tin plate and the number of corrugations or expansion rings. Furthermore, the sprung end of a can forms an arch supported by the side of the can and with some cans considerable pressure is required to force this arch down and make the end flat or concave again. If the ends were free to move in or out (as the pressure within the can became greater or less than the pressure without) then

Table 3, Combined Influence of Altitude and Storage Temperature on Vacuum

Altitude, mean temperature for the hottest month, maximum recorded temperature, and approximate vacuum or pressure in a can having a vacuum of 3.7 inches at 50° F. and sea level.

City—	Altitude Feet	Mean Temperature ° F.	Vacuum (in.) or Pressure (lbs.)*	Maximum Recorded Temperature ° F.	Pressure Pounds Per Sq. In.
Altanta, Ga.	1,032	78	0.2*	100	2.7
Baltimore, Md.	S. L.	77	0.7	105	2.25
Boston, Mass.	S. L.	71	1.5	104	2.1
Charlotte, N. C.	721	79	0.1*	102	2.2
Charleston, S. C.	S. L.	81	0.1	104	2.1
Cheyenne, Wyo.	6,062	67	2.0*	100	4.7
Chicago, Ill.	603	72	0.8	103	2.3
Denver, Colo.	5,279	72	1.9*	105	4.8
Galveston, Texas	S. L.	83	0.1	99	1.6
Helena, Mont.	4,157	67	1.0*	103	4.0
Indianapolis, Ind.	726	76	0.2	106	2.7
Key West, Fla.	S. L.	84	0.2	100	1.7
Milwaukee, Wis.	636	70	1.0	102	2.2
Nashville, Tenn.	450	79	0.0	104	2.3
New York, N. Y.	S. L.	74	1.2	102	1.9
Omaha, Neb.	1,042	76	0.9	110	3.3
Philadelphia, Pa.	S. L.	76	0.0	106	2.4
Phoenix, Ariz.	1,090	90	1.2*	119	4.6
Portland, Ore.	S. L.	66	2.1	102	1.9
Salt Lake City, Utah	4,230	76	1.6*	102	4.0
San Francisco, Cal.	S. L.	57	3.1	101	1.8
St. Louis, Mo.	455	79	0.1	107	2.7
St. Paul, Minn.	828	72	0.6	104	2.5
Seattle, Wash.	S. L.	64	2.3	96	1.3
Washington, D. C.	S. L.	77	0.7	106	2.4
Athens, Greece	160	80.6	0.1	......	....
Aukland, New Zealand	S. L.	67	2.0	......	....
Berlin, Germany	110	64.6	2.2	......	....
Bombay, India	S. L.	85.3	0.25	......	....
Buenos Aires, Arg.	S. L.	75.4	1.0	......	....
Cairo, Egypt	50	83.3	0.1	......	....
Cape Town, Cape Colony	S. L.	69.6	1.8	......	....
Colombo, Ceylon	S. L.	82	0.0	......	....
Havana, Cuba	S. L.	81.9	0.0	......	....
Hongkong, China	S. L.	81.5	0.0	......	....
Honolulu, Hawaii	S. L.	77.7	0.6	......	....
Lima, Peru	500	74	0.7	......	....
London, England	S. L.	63.1	2.4	......	....
Madrid, Spain	2.450	76.5	0.8*	......	....
Manila, P. I.	S. L.	83.5	0.1	......	....
Mexico City, Mex.	7.434	64.5	2.5*	......	....
Paris, France	200	64.9	2.1	......	....
Peking, China	121	78.8	0.4	......	....
Quito, Ecuador	9,000	55.4	2.6*	......	....
Rio de Janeiro	S. L.	77.7	0.6	......	....
Rome, Italy	100	76.3	0.8	......	....
Sydney, Australia	S. L.	71.2	1.5	......	....
Valpariso, Chili	S. L.	63.1	2.4	......	....

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*Pressure in pounds per square inch.
S. L. means sea level.

the ends of cans in the cannery which immediately after retorting are all sprung outward would collapse gradually and quietly. However they remain sprung for some time after the pressure within the can has become less than the external atmospheric pressure and then collapse with a sharp snapping noise.

Not only should the average vacuum be considered but also the percentage of cans having a low vacuum or none at all; for in some parcels the vacuum is exceedingly variable, ranging from 0 to 14 or 15 inches, and the percentage of those having no vacuum may amount to five or even ten per cent. Such a parcel if shipped to a warm climate, for instance, **would most certainly develop five or ten per cent of springers,** and require reconditioning with consequent suspicion as to the quality of the remainder of the parcel, or bring about rejection of the entire parcel.

For convenience table 3, giving the altitude and the mean temperature for the hottest month in the year in a number of the most important cities to which canned salmon is shipped, together with the maximum recorded temperature for some cities of the United States, has been included. No information giving the maximum temperature in the foreign cities was available. In order to show the effect on vacuum which these temperatures and altitudes would have, figures are included showing the theoretical vacuum (or pressure, as the case may be) which a can of average headspace would have whose vacuum at 50° F. was 3.7 inches. Most of the salmon is examined commercially at a temperature of 50° F. or less. For a vacuum higher than 3.7 inches add the difference between 3.7 inches and the vacuum in question to the figures given in the table; for figures less than 3.7 inches subtract the difference between 3.7 inches and the vacuum in question from the figures given in the table and the resulting figures will be approximately correct.

These values are taken from the curves in Figs. 4 and 5, and are based on the behavior of a one-pound tall salmon can containing 438 grams of distilled water and 29.92 cc. of headspace (about one-fourth inch) at 72° F. The values for pressures are based on the assumption that the can be rigid. However, the vacuum or pressure in a one-pound tall can of salmon having the same amount of headspace would change in about the same way.

Effect of Altitude on Vacuum

Practically all packing of fish is done at or near sea level, but shipments are made to points several thousand feet above sea level. As already stated, the average atmospheric (or barometric) pressure at sea level due to the weight of the envelope of air about the earth amounts to approximately thirty inches of mercury. This pressure is less at points above sea level. The following table shows the average atmospheric pressure at different altitudes up to 15,000 feet, together with the theoretical loss in vacuum in cans packed at sea level due to increasing altitude.

This table is concerned only with altitude and not with changes in temperature. An increase in temperature would result in a further loss of vacuum.

Table 4. Atmospheric Pressure and Loss of Vacuum at Different Altitudes

Altitude feet	Atmospheric pressure inches	Loss in vacuum inches	Altitude feet	Atmospheric pressure inches	Loss in vacuum inches
0 (sea level)	29.90	0.00	5,503	24.42	5.48
100	29.79	0.11	5,997	23.98	5.92
302	29.57	0.33	6,500	23.54	6.36
505	29.35	0.55	7,001	23.11	6.79
803	29.03	0.87	7,500	22.69	7.21
1,000	28.82	1.08	7,995	22.28	7.62
1,504	28.29	1.61	8,500	21.87	8.03
1,999	27.78	2.12	9,002	21.47	8.43
2,502	27.27	2.63	9,500	21.08	8.82
3,005	26.77	3.13	10,008	20.69	9.21
3,497	26.29	3.61	10,998	19.95	9.95
3,998	25.81	4.09	11,997	19.23	10.67
4,498	25.34	4.56	15,000	17.22	12.68
4,995	24.88	5.02			

Taken from Smithsonian Meteorological Tables, 4th rev. ed., 1918, pp. 136-137.)

If all the gas were removed from the headspace of a can of salmon, at sea level, there would be produced. theoretically, with the exception of a slight amount of pressure due to water vapor, a complete vacuum of about 30 inches. Any vacuum less than that is a partial vacuum, which means that some of the gas is still in the can and exerts a pressure; this partial vacuum is the difference between the pressure inside and the pressure outside the can. If the pressure inside and outside the can are equal, there is of course, no vacuum; if the pressure outside is the greater there is a partial vacuum in the can; if the pressure inside is the greater there is an excess pressure in the can which will register on a compound vacuum-pressure gauge. When a can is once tighty sealed it is obvious that no gas can get in or out and consequently with temperature remaining constant there will be no change in the pressure inside the can except that produced by the disappearance of gaseous oxygen. Suppose we have a can with 6 inches of vacuum (or 24 inches of pressure, 30-24) at sea level where the external pressure is 30 inches. If this can is shipped to Cheyenne, Wyo., at an elevation of 6,054 feet, where the external pressure is 24 inches, the external and internal pressures will balance and the six inches of vacuum will disappear; there will be neither vacuum nor pressure in the can when tested with a vacuum-pressure gauge. Now, if this can be sent to Leadville, Colo., at an elevation of 10,200 feet, the internal pressure will still be 24 inches while the external will be only 20 inches—a difference of 4 inches. In other words the can, if tested with a compound vacuum-pressure gauge will now have a pressure of 4 inches or 2 pounds and will undoubtedly be a springer. Table 5 shows approximate changes in vacuum between sea level and various well-known cities due to altitude alone. If at the same time the temperature increased, the gases in the can would tend to expand and further decrease the vacuum.

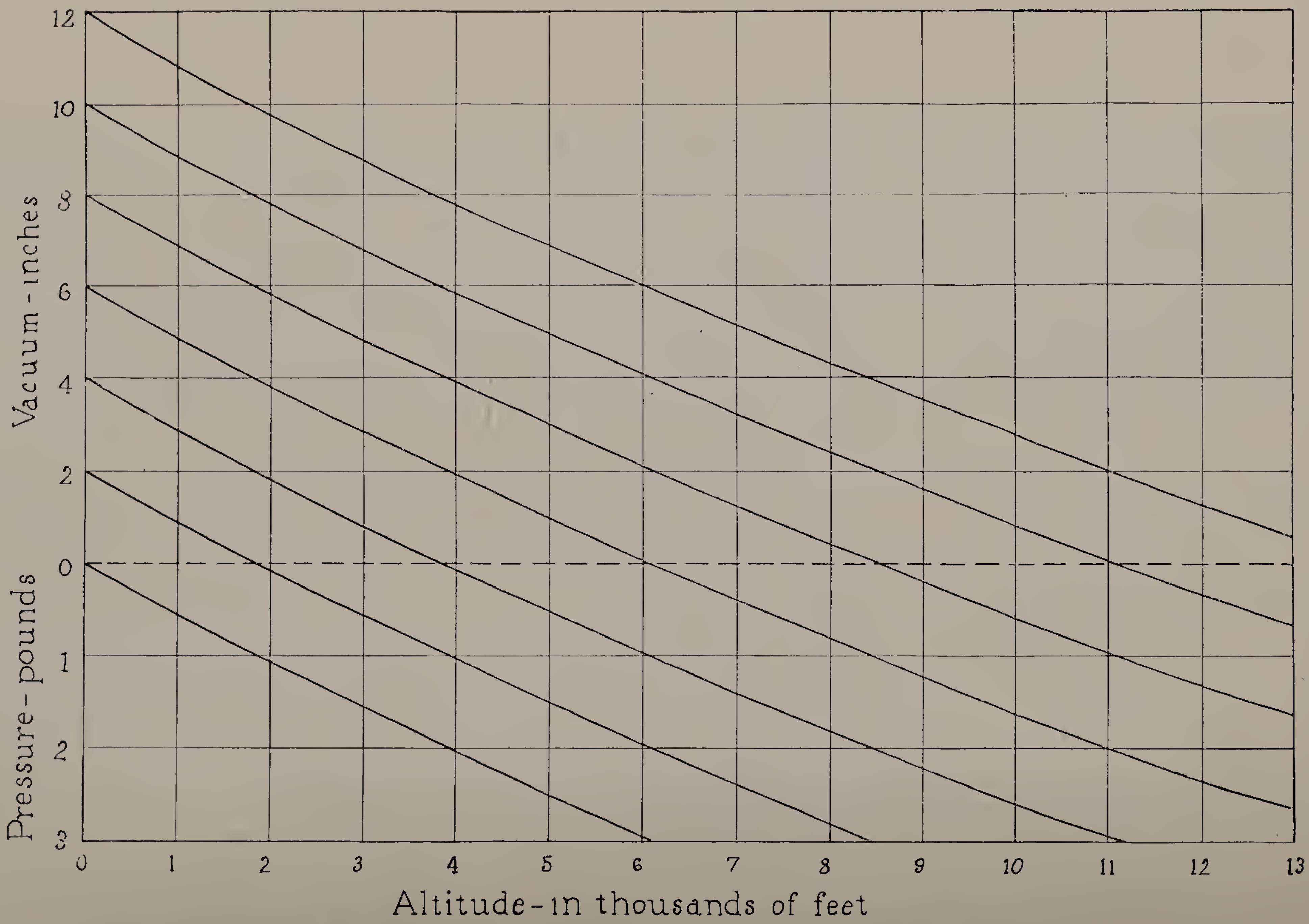

Fig. 5—Variations in Vacuum Caused by Changes in Altitude.

Table 5. Influence of Altitude on Vacuum

Locality	Altitude feet	Approximate vacuum or pressure in inches or pounds.						
Seattle, Wash. Boston, Mass. New York, N Y. New Orleans, La.	0	10	8	6	4	2	0	
St. Louis, Mo.	455	9.5	7.5	5.5	3.5	1.5	0.2	
Chicago, Ill.	631	9.3	7.3	5.3	3.3	1.3	0.3	
St. Paul, Minn.	911	9.0	7.0	5.0	3.0	1.0	0.5	
Atlanta, Ga.	1,033	8.9	6.9	4.9	2.9	0.9	0.5	
Ashville, N. C.	1,986	7.9	5.9	3.9	1.9	-0.0-	1.0	
Missoula, Mont.	3,197	6.7	4.7	2.7	0.7	0.6	1.6	
Ogden, Utah	4,310	5.6	3.6	1.6	0.2	1.2	2.2	
Denver, Colo.	5,183	4.8	2.8	0.8	0.6	1.6	2.6	
Cheyenne, Wyo.	6,054	4.0	2.0	-0.0-	1.0	2.0	3.0	
Flagstaff, Ariz.	6,886	3.3	1.3	0.3	1.3	2.3	3.3	
Leadville, Colo.	10,200	0.6	0.7	1.7	2.7	3.7	4.7	

Note—Figures to the left of the broken line represent vacuum in inches of mercury and figures to the right pressure in pounds per square inch. These values are based on altitude alone. An increase in temperature would cause a further decrease in vacuum. The values apply to cans of all sizes, but the cans are assumed to be rigid.

For a better understanding of the changes which take place in the vacuum of canned salmon with changes in altitude, the curves given in Fig. 5 have been prepared. These curves are derived from the data given in Table 4.

The dotted line across the page marked "O" represents the point at which the cans have neither vacuum nor pressure; above this line all values represent vacuum in inches of mercury and below all values represent pressure in pounds per square inch. Horizontal lines represent vacuum or pressure, while vertical lines represent altitude in feet. Vacuum or pressure in a can of salmon will change with changes of altitude very closely according to the curves which have been drawn. **To use these curves:** At the foot of the vertical line, find the altitude which is nearest to the altitude at which the vacuum of the can has been determined; next locate the vacuum at the side of the page which is nearest to the vacuum found in the can of salmon, follow the **horizontal** line representing the vacuum until it crosses the **vertical** line representing the altitude. The point of intersection will fall near some curve on the chart. Now the can in question will vary in vacuum or pressure with changes in altitude approximately in accordance with this curve. For example, if a can at sea level (0 feet altitude) has a vacuum of 2 inches, it will be seen by following the nearest curve that at an altitude of less than 2,000 feet (where the curve crosses the zero (0) line it would have no vacuum, while at an altitude of 6,000 feet it would have a pressure of about 2 pounds. The vacuum or pressure for any other altitude lies on this curve at the point where the vertical line representing that altitude crosses the curve. By following the horizontal line nearest to this intersection to the edge of the chart the vacuum or pressure may be read.

Again, suppose the can in question has a vacuum of 5 inches at an altitude of 3,000 feet. The vertical line representing 3,000 feet and the horizontal line representing 5 inches intersect near the curve which reaches the edge of the chart at figure 8 and crosses the zero line where it intersects with the vertical line representing 8,500. This means that at an altitude of 8,500 feet this can would have no vacuum, while at sea level it would have had 8 inches, furthermore if shipped to Leadville, Colo., at an elevation of 10,200 feet it would have had a pressure of nearly a pound.

In this connection, consideration must also be given to the route over which the salmon is to be shipped. Cans having a low vacuum may become springers in going over one of the mountain passes, some of which are very high. A notable example is the one in the Rocky Mountains over which the Denver and Rio Grande Railroad passes. Cans having a vacuum of 11 inches at sea level will have no vacuum at this elevation (11,000 feet) provided the temperature is the same as that at which the cans were tested at sea level. Cans having less than 10 inches of vacuum would be likely to develop a pressure and to become springers. As already pointed out, cans having once become springers may remain springers when the storage conditions have so changed as to again produce a slight vacuum within the can. Therefore, cans which have become springers while going over these mountain passes may remain springers even after the cans have reached a lower altitude. The jarring which the cans receive in transit or in handling tends, however, to cause such springers to return to a normal appearance. That this jarring is not sufficient to cause all of them to return to normal is shown by a recent express shipment of springers from Colorado to Seattle. Over half of the cans were still springers on arrival, most of which had a slight vacuum.

Springers Result From Altitude

It can readily be seen that altitude exercises a surprising influence on vacuum. Very recently two shipments of salmon to Colorado required reconditioning for the reason that they contained a considerable percentage of springers. It was known that the shipments contained many low-vacuum cans and undoubtedly all or nearly all of the springers were due to the effect of increase in altitude on these low-vacuum cans. If these cans were shipped to sea level in some cool section, it is very probable that many of them would return to normal. In this case the shipper would not lose the cans but would be put to considerable trouble and expense. Moreover, as already stated, there is a growing tendency among food officials to prohibit the return of swelled or questionable canned goods to the packer.

It should be understood that tables 4 and 5, and Fig. 5 include changes due to variation in altitude alone. An increase in temperature has the effect of lowering the vacuum while a decrease in temperature increases the vacuum. To repeat, increasing either the altitude or the temperature reduces the vacuum while decreasing the altitude or the temperature increases the vacuum. If both temperature and altitude are increased or decreased, the resulting changes in vacuum due to each factor must be added together to give the total increase or decrease in vacuum. If one of the factors increases while the other decreases, the resulting changes in vacuum due to each factor must be subtracted one from the other to give the net increase or decrease in vacuum.

Care should be taken in handling salmon that the cans are not dented, both for the sake of the appearance of the cans and also because such denting causes a corresponding loss of vacuum due to the decrease in volume and corresponding increase of pressure of the enclosed gases.

General Discussion

Since this investigation on the proper vacuum for canned salmon was begun several instances have been reported in which insufficient vacuum has resulted in loss to the shippers. Numerous other cases have occurred in the past and it is believed that nearly all salmon packers at some time in their business history have suffered losses from this cause. It is, therefore, felt that this paper will be of service to the industry by emphasizing the importance of proper exhaust, and by pointing out that parcels of canned salmon known to have a low vacuum should not be shipped to places having a high altitude or a warm climate.

An average vacuum of **ten or twelve inches** is very desirable in cans of salmon and the parcel should not contain more than a very small percentage of cans having a low vacuum or none at all. Such low vacuum cans may result from insufficient exhaust, overfilled cans, or occasionally from loosely rolled seams. The use of can ends having several expansion rings or corrugations, while ensuring a normal appearance to the can even though there is a considerable pressure within it, is considered an unsafe practice because neither the packer nor consumer has the usual protection against swells caused by bacterial spoilage.

Although this paper was written for the salmon industry, it is recognized that much of the information given may be of value to packers of other products. In dealing with these other foods the problem becomes somewhat more complicated, however. For instance, acid fruits and berries are likely to attack the metal container, forming hydrogen gas which gradually reduces the initial vacuum to zero and will in time produce a pressure within the can with consequent springers or swells. Such cans, although not necessarily unfit for food, are often unmerchantable. The formation of hydrogen may be kept at a minimum by storage in a cool place. The corrosion of the metal container by acid products appears to increase in the presence of oxygen. The tendency of the packers, therefore, is to attempt to remove all of the air from the can by filling it completely full. However, the fruit may contain oxygen within its tissues and the syrup or brine added may also contain dissolved oxygen unless it has been recently boiled.

There are numerous other factors which may affect the vacuum in cans of food, among which are the following: Carbon dioxide gas is found in the headspace of nearly all classes of foods. Now this gas is soluble to some extent in water, but its solubility decreases with increasing temperature. Therefore, cans which have a certain vacuum at a low temperature will lose a part of this vacuum when the can is warmed, by the changing of a part of the dissolved carbon dioxide to the gaseous form when it occupies a much greater volume and reduces the vacuum somewhat.

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